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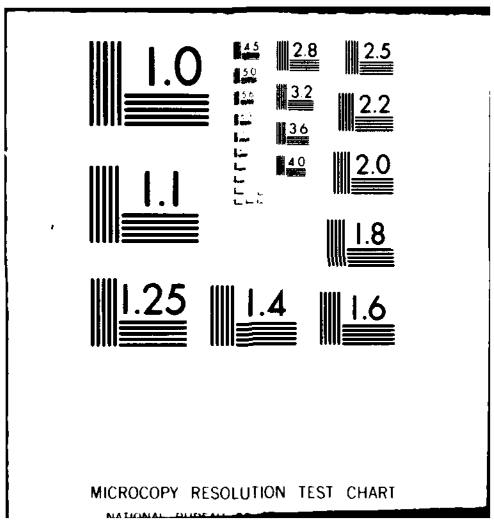
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DECREASING AIR POLLUTION IN AFFORESTED AREAS

by

B. Glowiak, K. Zygmunt

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Decreasing Air Pollution in Afforested Areas
B. Glowiak, K. Zygmunt

The article presents the problem of changes in the structure of emission during the flow of a mass of air polluted by dust and gases over afforested areas. The possibility of decreasing the state of the atmospheric pollution by proper selection and spatial formation of tall greenery.

The efficient separation of industrial areas from which are pollutants are emitted to inhabited, agricultural and recreational regions can be guaranteed by protective belts of tall greenery having proper spatial formation or by forest areas having proper specific composition of tree covers and their structure. Tall greenery can, in the battle with air pollutants, fulfill both a passive protective role, decreasing the access of dusts and gases to areas protected by the isolating activity of a wellset barrier of treecover, and an active protective role by activity reducing pollutants, establishing a filter for dust pollutants and thinning the concentration of gases and absorbing them simultaneously.

Conditions of Tree Cover Protective Action

A forest or protective tree cover belt a can effectively reduce pollutants only when the concentration of pollutants will not exceed amounts of

threshold concentration. The amount of threshold concentration of a given pollutant was defined as that concentration of dust or gas which even during longest reaction does not produce harmful results proven experimentally in the development and vegetation of plants (8). The value of threshold concentration $S_?$ depends both on the type of pollutant and the specific qualities of tree cover (8).

The degree of damage to tree covers by emission is proportional to the product of the time of reaction and the amount of concentration of the polluting compound in the air, which was expressed in the form (8):

$$L \cdot S = C \qquad (1)$$

where:

L -- reaction time of pollutants on plants and tree covers,

S -- concentration of polluting compound in the air,

C -- amount determining the degree of damage to plants.

Damage to the tree covers which permit their protective reaction occurs, thus as the result of the flow, within a certain time interval, of pollutant concentrations greater than threshold concentrations.

The average concentration of $\bar{S}$ of a given pollution for the time interval was expressed (8) by the sum of the products $S \cdot L$ divided by the time L,

for which this sum is calculated:

$$S = \frac{1}{L} \sum_{i=1}^{i=s} S_i \cdot L_i \qquad (2)$$

where:

L -- reaction time of air pollution on plants,

S_i -- concentration of pollution appearing in time period L_i,

S -- amount of time periods L_i.

Damage to tree covers in the function of concentration of gas pollutants and of duration period of emission can have a severe and chronic nature.

Severe damage (burns) caused by the emission of gases of high concentration, reacting in a short time interval, are limited usually to an area situated in direct environment of the emission sources (1, 17). As a result of the appearance of striking, high gas concentrations, the tree cover deadens.

Chronic damage takes place because of long lasting reaction on the tree cover of the continual emission of dusts and gases having lower concentrations and less toxicity. They encompass by their range greater than severe surface damage to forests and appear gradually in the tree cover within measure of the application of continual emission of dusts and gases (1, 17).

The earlier and clearer the symptoms of this damage appear the greater the susceptibility of the qualities of the trees creating the given tree cover to the reaction of the air pollutants. Damage to the assimilating organs of the trees (chiefly coniferous trees) is the earliest and most important revelation of negative results of the reaction of industrial air pollutants on tree covers (1).

Reaction of Gas and Dust Pollutants on Tree Covers

The reaction of individual types of tree cover to the emission action, appearing to the degree of damage to the assimilating apparatus of the trees, independent of the essential influence of other factors, in a decisive degree will be defined by the composition and amount of pollutant concentrations. Gas pollutants, more aggressively than dusts, act particularly harmfully to the tree covers. Above all, the magnitude of their concentration and the susceptibility of the type of trees to the defined gas pollution determines the degree of harm to tree covers by gas pollutants. The degree of harm of gas pollutants depends also on:

--the reaction time of gas pollution on the tree cover,

--the age of the tree cover,

--the frequency of appearance of fog,

--the temperature and humidity of air,

--the force of the wind,

--soil conditions and stadium of physiological activity.

Gas pollutants cause the greatest damages in wood cover during relatively momentary but repetitive gas pollutant emissions having great concentration, arising as a consequence of average gas exhausts (18). Then there takes place severe damage in the form of burns of assimilating organs of trees, so-called nercoses. The most exposed to danger are the borders of the tree covers, situated in the direction of prevailing winds from the sources of emission. The less susceptible types of trees located in border zones of forest surface areas from the characteristic "smoke" mold.

Retention of the protective abilities of bordering tree covers TO the faces of impacts of air masses polluted by gas will require creation, in the directions of the prevailing winds from the sources of emission, of a proper border, composed of types of trees and shrubs especially resistant to the pollutants emitted. To these types belong: black alder, mamilliform birch, black pine, red oak and poplar (16).

The most universal gas pollutant causing the greatest damage in wood covers is sulphur dioxide. SO_2 causes chlorophyll decomposition, reduced intensity of breathing and assimilation, evokes strong disturbances in water plant farming, reducing the growth of thickness of ligneous plants (2, 4). A particular damage of sulphur dioxide to tree covers is caused by the assimilation of SO_2 instead of CO_2 in the photosynthesis process (4). An average day

concentration of 0.05 mg./m.^{3} is considered as the threshold of toxicity of this gas in its reaction ot to the wood cover (18). SO_2 even in this concentration in the air produces obvious damage not only in spruce and common pine, but also in oak and beech (10). Observations of long duration proved that an increase in the height of spruce trees can yield to restraint even at a steady concentration of about 0.01 mg./m.^{3} SO_2 (11). Complete checking of photosynthesis takes place at a concentration of 0.4 mg./m.^{3} SO_2 (10).

Of the coniferous types, the least susceptible to SO_2 activity are the black pine (1, 6, 18) and European larch (1) which can tolerate long lasting but low SO_2 concentration (clearly damaging the spruce), but is very sensitive to the short lasting activity of greater concentrations (10).

The reaction of dusts on plants is less harmful than gases. Dust pollutants can act toxically on ligneous vegetation or can also mechanically harm tissues of the assimilation apparatus of trees. A chemical toxic reaction occurs when the dusts falling on the leaves of the trees cause the appearance of acid foci having great concentration which can produce burning of leaf surfaces.

Mechanical damage of tissues arises due to the plugging of tracheae which makes the exchange of gas substances inside the leaves with the atmos-

phere difficult. In connection with this, finely dispersed dust is more harmful to plants than coarse fractional dust (4, 16). Moreover, decreased growth of plants due to negative action of the dust is indicated.

Resistance of Tree Covers to Emission

Air pollutants react harmfully to all trees and there are no types completely resistant to emission (10). We can only speak of a greater degree of susceptibility of individual types of trees to dust and gas pollution or of their relative resistance (10, 19). Relative differences in resistance to emission indicate that in the case of every type of tree cover growing in an open area such a concentration of gas pollution and such a duration period of emission can occur which suffice to deaden the tree.

Resistance of the tree cover to industrial emission is thus, above all, a function of the amount of gas concentration and duration period of emission, to a lesser degree, however, of the specific qualities of the tree covers. Nonetheless the proper selection of types of tree covers relatively resistant to gas pollutants and adapted to dust collections is one of the chief factors which can determine the protective possibilities of tree covers. The most susceptible to injury are coniferous types such as: spruce, fir, and pine, in which the life of the assimilating mechanism lasts several years (1, 6, 18, 19). The least susceptible coniferous species to emission of gas and dust air pollutants is the

black pine which has strong organs of assimilation (1, 6, 14, 18).

The deciduous trees, among them in particular mamilliform birch, black alder, red oak and poplar can be counted in those species decidedly more resistant to the reaction of industrial pollutants than fir, spruce and common pine (16). Many authors consider the red oak (1, 4, 18) and black pine (1, 6, 14, 18) as types relatively resistant to SO_2 activity. Among the coniferous and deciduous species, that species is more resistant to emission which has stronger assimilative organs and grows slower (19). Quick growing trees with large assimilative capabilities are the most susceptible to toxin emission (19). In fertile and humid collections there is an absorbtion of emission activity. Species growing in collective conditions characteristic for them will show greater resistance.

Filtering Activity of Tree Cover

Purifying polluted air by tree cover depends on the fact that the forest or strip of protective forestations acts as a filter in relation to dust pollutants as a result of the attachment of dust granules to the surface of needles or leaves. Dust remaining on parts of the trees, chiefly on the surface of the assimilation apparatus, is rinsed off to the ground by rains.

Effective filtering activity of a tree cover can take place only under suitable conditions such as:

-- the magnitude of pollutant concentrations in masses of air flowing to tree-covered areas,

-- altitude of emission appearance,

-- placement of tree cover barrier toward the direction of prevailing winds from sources of emission,

-- vertical and horizontal structure and width of tree-covered area,

-- type of forestation.

The effectiveness of the filtering activity of the tree cover will depend above all, on the magnitude of the dust load in the air masses. With an excessive load and small frequency of ranfall a complete covering of leaves or needles by dust can take place and thereby the force of the attachment will decrease, thanks to which the dust is stopped by the assimilation apparatus of the tree. To realize the filtration function of the tree cover a deciding factor will be the determination of the magnitude of the limiting loads of air masses by the dust and retaining the state of pollution of the atmosphere by dust on their level.

The vertical and horizontal structure of the forested surface has essential significance on the purifying and filtering effect. The largest re-

duction of pollutants can take place on the forested surface having a layered structure, where there exist favorable conditions for increased, in relation to the open turbulent space, air exchange. Filtration courses chiefly in the zone of tree heads. In the tree head zone there are frequent changes in the directions of air current flow, which meet there with the greatest resistances and in effect particles of dust separate from the air stream (5). Besides the layered structure of a forested area, loosely compact tree covers, which simplify air movement and consequently, emission separation, create optimum filtration conditions. At the same time, such tree covers are durable. To a great degree compact tree plantings act as an obstacle in a flow and through air masses are by-passed by the top due to directing, through a tree cover barrier, a stream of air over tree heads. This is the reason for the displacement of pollutants in upper and lower layers of the air over a forested surface. Moreover compact tree plantings, changing speed and direction of the current of the dust-filled air, cause the accumulation of dust pollutants in front of the border of a forested area (7). On the other hand, an increase in the concentrations of gas pollutants (SO_2) in front of a forest has not been proven (9). Tests on the concentrations of dustiness over open area and over the forest indicated a very clear increase in dust concentrations at the edge of a forest, and consequently a decrease in dustiness within measure of the increase of distance from the edge of a forested area (7).

Counteraction to excessive accumulation of dust pollutants in front of a border of a forested area will require the formation of wind channels in tree covers having a large degree of compactness (perforation to 40%). Introducing changes in the horizontal structure of tree covers through suitable differentiation of compactness ensures good conditions for movement of lower layers of dust-filled air in a tree-covered surface area and thereby permits emission separation and filtration.

Under conditions of good ventilation of protective forestation having loose compactness (perforation from 40 to 50%), air currents will both pass over the tree cover and penetrate through it, which will influence the change in the characteristic of air currents also in a lee area. On a lee side there is no whirl of streams of air currents and increase in value of dust concentrations as there is in the case of compact forestations, acting as obstacles in an air flow. On the other hand it can be assumed that due to the relatively uniform strata of energy of the movement of streams of lower and upper layers of air, the air current passing through the tree cover belt will counteract the rise, on the lee side of the tree cover belt, of a negative pressure zone and whirls of streams of air currents, passing over the tree cover. Consequently, it does not follow how we can assume the increase in concentrations of pollination beyond the protective tree cover belt.

Width of Afforested Surface With Active Filtering Operation

It should be assumed that the width of the filtering tree cover belt will be a function of the degree of irregularity of the head profile and altitude of appearance of pollutant emission. Under conditions of an afforested surface area having a large degree of uneven head profile a turbulent air exchange increases and consequently, the width of the tree cover belt will be smaller, necessary for the effective filtration process of the lower layers of polluted air.

Air currents penetrate into the depth of the forested surface freely at a distance of about 100 m. (13), on the other hand, the largest part of the pollutants, contained in the air flowing to the forested area, is absorbed by the extreme belt from 100 to 300 m. wide (8). Consequently, we can assume that the tree cover belt 100 to 300 m. wide with an uneven head zone and loose compactness (perforation of from 40 to 50%), comprised of relatively resistant deciduous trees accomodating the collection, fulfills for the protected area the role of an effecient screen, filtering the polluted air. The dam of tall plant growth of proper width and structure most efficiently filters the polluted air when it is located perpendicular to the direction of the prevailing winds from the source of emission. It should be assumed that there then takes place the most advantageous conditions for protective functioning of tree cover on the faces of impact of polluted air masses.

Efficient purification of lower layers of dust-filled air as the result of the filtering action of the air cover is moreover conditioned by the appearance of dust emissions at low (from 5 to 15 m.) altitudes (7). Purifying the masses of air from the dust pollutants arising from emitters exceeding the barrier of trees will require considerable wider tree planting surface areas than when the dusts emitted are from lower sources of emission. Dust pollutants in this case will shift themselves in their entire mass over the tree covered area, becoming the surface with an increased degree of development, with relation to the open area. Over this surface the movement of the air is characterized by increased turbulence (15).

Precipitation of finely dispersed dust pollutants, displaced over the forest surface, takes place to a large degree due to accelerated--chiefly through increased air turbulence--coagulation process of dust particles over the tree heads, which leads to the rise of a mass of dust particles and their speed in falling in the forest (5). Through the increase of dust fallings in the forest the pollination concentration over the forest decreases, and consequently, there occurs a partial purification of dusts from the air masses. A frequency of atmospheric fallings greater than in an open area, and the humidity of the air over a treed surface are additional factors favoring the increase of dust falling in the forest through accelerated coagulation of dust particles over the tree head zone (9). There exists a clear dependence of speed of dust fallings U_p

on the type of covering and the depth of the ground, which the comparison given by Chrosciel (3) indicates in Table 1. The data indicates that e. g., the value of the falling speed of mineral dust for a forested area was several times greater than for an open terrain. The possibility of precipitating dust from a dust-filled mass of air through forest areas is thus considerably greater than through ground covered by a low grassy vegetation (3).

Table 1. Speed of Dust Fallings Depending on Ground Type According to Various Authors

Type of pollutant	Type of area	Speed of falling U_p m/s	Author
Local dusts	city	0.01-10	Hosker (1973)
Metallic dusts	deciduous forest	21.1	White, Turner (1970)
Mineral dusts	forest	1.2-20.5	Waldren (1970)
Mineral dusts	meadows, fields	0.1-5	Van der Hooven (1967)
Mineral dusts	grass	0.1-5	Hosker (1973)

Decreasing Air Pollution with Harmful Gases Through Tree Covers

Tree covers react in a purifying way also concerning gas pollutants of the air, nevertheless this influence has not yet sufficiently been examined.

The purifying action of a tree cover in the case of gas pollutants depends on diluting the concentration of gases (emission separation) in effect of the reaction of trunks, boughs, branches, and leaves of trees and the simultaneous absorption of parts of gases through the assmilation apparatus of trees.

Tall greenery indicates particularly great capability to absorb sulphur dioxide (12). This takes place, as already mentioned, as the result of assimilation of SO_2 rather than CO_2 in the process of photosynthesis.

Gas pollutants propagate chiefly over an afforested surface, which was indicated by examinations of the vertical decomposition of SO_2 concentrations in the forests of the Niepolomick Virgin Forest (9). Such a vertical decomposition of concentrations can be the result chiefly of the thermo-dynamic conditions of the air in a forest environment. The appearance of considerably lower SO_2 concentrations in a zone under tree heads in relation to concentrations of this gas over a forest surface can also be the result of intense SO_2 absorption through the assimilation apparatus of trees (9, 15).

Tests on the spatial decomposition of SO_2 concentrations indicated the effect of the increase in the degree of development of the surface over the head zone on the changes in value of concentrations of gas pollutants in masses of air flowing over a forested terrain.

Also in the case of gas pollutants the data concerning the speed of settlement in a function of the type of terrain covering in relation to SO_2 indicate the clear dependence of the speed of settlement and consequently of the changes of gas concentrations from the type of ground (3), which Table 2 shows. Similarly as in the case of dust pollutants the settlement speed of SO_2 for ground covered by a forest was considerably greater in relation to ground covered by grassy vegetation. Greater speed of settlement of gas pollutants for forests can result only from greater--in relation to open area--intensity of diffusion and greater capability to absorb gases through the forest (3).

Table 2. Speed of Settlement of SO_2 of Function of Ground Type According to Various Authors (given according to S. Chrosciel (3)

Type of terrain	Speed of Settlement U_p m/s	Author
Average for terrain of Great Britain	1.8	Chamberlain (1961)
Water	0.9	Eriksson (1953)
	1.0	Scriven, Ficher (1975)
Grass	0.8	Scriven, Ficher (1975)
	0.3-2	Scheppard (1974)
Deciduous forest	1-15	Scheppard (1974)

Wind velocity has an essential bearing on the magnitude of SO_2 absorption through the tree cover. Latocha (11) offers according to Jirgle and Kucera that at the same level of SO_2 air pollution in places th where there is a greater wind velocity there is also a greater SO_2 absorption.

Filtering Capabilities of Various Tree Covers

Checking dusts through a tree cover is different depending on the kind and species of trees and the time of year. According to American testing, coniferous trees decrease air pollution (in a range of very fine dusts with a granular diameter of about 0.1 μm.) about 34%, and deciduous trees about 19%. Consequently, coniferous trees have greater filtering capabilities than deciduous trees. It was shown that 1 ha. of a spruce forest retains about 37 tons of dust, while a pine forest 34.5 tons of dust (16). Of deciduous trees the best filtering effects are shown by elm, lilac and maple (16). Quantities of retained dust by individual types of deciduous trees are varied and amount approximately to 1 m^2 leaves: elm--4 g., lilac and maple--1.6 g., and linden--1.3 g. The poplar which holds less than 0.5 g./m^2 of dust shows the least filtering capability.

The amount of dust retained is decided on, above all, by the surface of the foliage or needles of the tree covers. Air pollution over tree heads decreases during the foliage period aby about 20 to 40%, while, in a leafless state by

about 13 to 18% in relation to open areas (16).

Amounts of retained dust by a tree cover, defining its filtering capabilities, will depend both on the size of the foliage surface and force of attachment of dust particles to the leaves or needles of the trees and the magnitude of the load of the air mass by dust and on the momentary condition of the atmosphere. The most favorable atmospheric conditions for the retention of dusts by tree covers take place during windless weather or with small wind velocities.

Concluding Remarks

The course of the separation process of emission and filtration during the flow of a mass of dust-filled air by a tree cover is presented only descriptively. Closer knowledge of the conditions under which the filtration process can run, and consequently the establishment of a correlation between the factors which can decide its effectiveness, require examinations of the vertical decomposition of pollutant concentrations in a forest environment (relative to short periods of time) connected with simultaneous meteorological and biological observations of the tree cover in an afforested surface area included in the examinations. Then complex examinations of this type could be the foundation for the quantitative handling of the mechanism of

emission absorbency of tree covers. For the illustration and analysis of the influence of tree covers on pollutant concentration in the air and on a small scale course of the filtration process, model examinations in an aerodynamic tunnel will be useful. These examinations, giving definite approximation of actual conditions, make it possible to obtain optimum dynamic conditions of an afforested terrain for the flow and filtering of a mass of dust-filled air by the tree cover. Model examinations, as well as results of field measurements of vertical and spatial decomposition of pollutant concentrations in a forest environment, will be useful also to verify the essence of the conditions of the filtration process presented in the article.

Protection of atmospheric air from pollution has as its purpose the prevention of excess allowable concentrations of substances in atmospheric air and the gradual decrease of substances introduced to atmospheric air by factories, motor vehicles, dumping grounds, and other sources of pollution.

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